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R&D for Better Nuclear Security: Radiation Detector Materials

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Judith Kammeraad†, 3rd speaker
R&D for Better Nuclear Security: Radiation Detector Materials

I am going to talk about the need for better materials for radiation detectors. I believe that government investment in this area can enable transformational technology change that could impact domestic nuclear security and also national nuclear security in some very positive and powerful ways.

I'm not going to give you a lecture on how radiation detectors work, but I am going to tell you a bit about today's off-the-shelf technology and why it is not sufficient, what we need, and what security benefit you could get from improvements. I think we're at a critical point in time for some very impactful investments. In particular I'm going to focus on the use of gamma-ray radiation detectors at ports of entry.

Not long before DHS was formed, Congress decreed that counter measures against the delivery of radiological and nuclear threats would be put in place at US ports of entry, under the authority of US Customs (later Customs and Border Protection in DHS). This included the screening of all cars and trucks passing through a port of entry. Existing off-the-shelf radiation detectors had to be selected for this purpose. Plans were made to make the most of the available technologies, but there are some inherent limitations of these detectors, plus the operational setting can bring out other limitations.

First, I'd like to give just a bit of background. A radiation detector detects the presence of a nuclear material by measuring the signature radiation emissions of that material. The ability to detect the signature gamma-rays depends on a number of things, some of which we can affect and some of which we cannot. The laws of physics will not change. How many gammas per second are released from a nuclear material, such as uranium or cobalt? What is the energy of those gamma-rays? How far away is the object from the detector? How well shielded is it?

You cannot change the natural emissions of the nuclear materials. But you can change the conduct of operations to a degree - for example, by constraining how far away the detector is from a truck coming through a port-of-entry. Another limitation is how well the detector can or cannot distinguish a potential nuclear or radiological threat from the radioactive things that aren't threats. In fact that world is full of radioactive things that can be detected. For example, buildings like this one contain beautiful granites and marbles –uranium and uranium daughters are typically present in these materials. You're getting a very small dose of radiation today from the beautiful marbles in this building. These are radioactive things in the environment that do not usually hurt us. In commerce you will find that some normal shipments contain radioactive materials. For example, bananas are high in potassium, and emit a strong potassium-40 radioactive signature. People who have recently received a nuclear medicine scan with technicium-99 will emit the signature of that radioactive substance for a short time after treatment and will be detected. These and other radioactive things in normal commerce will be detected, and the operational plan for the detection system must clear these "false alarms" as promptly as possible so that commerce is not impeded. This is a strong driving force behind the need for better detector materials.

The ability to distinguish between different radiation signatures is the key. For an analogy, imagine a telescope. The astronomer needs a telescope with excellent resolution so that two stars that are very close together in the sky can be distinguished or "resolved" from each other. Similarly, gamma-ray detectors need to have excellent energy resolution so that different gamma-ray energy signatures can be distinguished from each other quickly and with confidence. Operationally speaking, our ability to detect a radiological or nuclear threat with gamma-ray detectors depends on how well we can resolve the gamma-ray signature of the threat object from all other benign signatures and from local background radiation.

For detection of radiological and nuclear threats at a port-of-entry, we want to maximize the probability of detecting a threat while minimizing the false alarm rate. These quantities are captured in something called a ROC curve (receiver-operator curve), which takes into account the particular operational situation. With the ROC curve in hand, the operator can make trade-offs between the probability of detection and the false alarm rate. Generally speaking, the operators can improve the probability of detection if they can handle a higher false alarm rate, but the time and cost required to handle false alarms can quickly become excessive, which in turn sets the limit for the probability of detection. Ultimately this means that the benefit to security is limited by false alarms.

There are ways to break through this limitation, and one important way is by improving detector energy resolution, which in turn improves both the probability of detection and the false alarm rate. Both factors depend strongly on detector resolution -- a factor of two improvement in energy resolution provides an order of magnitude improvement in both the probability of detection and the false alarm rate. That is a very significant improvement and has significant benefits to security.

So how good does the energy resolution have to be? As shown in a recent study (reference 1) sponsored by DNDO, the desired energy resolution for gamma-ray detectors is about 1%.

How do today's off-the-shelf gamma-ray detector technologies compare to that? Sodium iodide, a well know scintillator, has 7%-8% resolution, so it's not good enough. Plastic scintillators, like those used in portal monitors, have virtually no ability to resolve different gamma-ray signatures; they just tell you that a radioactive material is nearby. They have a useful role in operational settings, because they alert the user to the presence of radiation in a vehicle or truck, but they don't give much indication to the nature of the radioactive material. High purity germanium has excellent resolution (less than 1%) but it's very expensive, and it's impractical to use at a port-of-entry, because it requires cryogenic cooling. Cadmium zinc telluride (CZT) has been around for more than ten years and has about 2% resolution – not quite good enough. It's enticing and maybe the researchers will find a way to achieve 1% resolution, but CZT is also very limited by the fact that we can't make the material any larger than a few cubic centimeters – smaller than your thumb. We need larger detectors than that for many security applications.

We need a detector material that can be made in relatively large sizes, that can function at room temperature, and that has 1% energy resolution, all at reasonable cost. There has been some investment in this area of research in the past 5 years, as Parney Albright pointed out in his introduction. In particular there are coordinated investments by DNDO in DHS, by DTRA in DOD, and by NA-22 in DOE. As a result of these investments and advances that are occurring elsewhere in the discipline of materials science, there are some interesting developments that could lead to a breakthrough in detector materials in the near future. Examples are transparent ceramics, non-toxic organic crystals, nano-composites, and more. Further government investment if needed here, not only in research to identify candidate detector materials that could yield 1% energy resolution, but also to develop the methods to scale up the production of such materials to commercial quantities.

I wish I could say we are in an era now when we could simply identify the right detector material from first principles in science. Unfortunately, it is still largely a matter of empirical discovery and some degree of luck. While there are significant materials modeling capabilities in the scientific community, we need solid state materials models that allow us to design the material and the detector from the ground up. Government investment is also important in this area of research.

How will these government investments benefit security? A factor of ten improvement in the probability of detection, without increasing the false alarm rate, means not only that we are better able to detect a radiological or nuclear threat at a port of entry. It also means that we improve the potential for deflecting an attack and for deterring an attack. The experts say that what deters terrorists from attacking is the fear of failure and the shame that comes with failure. Even a moderate improvement in the probability of detection may increase the terrorists' fear of failure and increase the potential to deflect or deter such attacks.

A further benefit is that we can improve nuclear security at US ports of entry without disturbing the flow of commerce, because fewer vehicles would have to be stopped to resolve false alarms. This is critical in today's economy. Better detector materials would also benefit a wide variety of other national nuclear security applications as well as medicine, especially nuclear medicine diagnostics.

In conclusion, I think we're at a point where radiation detection technology from the past 40 years is on the verge of significant advances that can strongly impact nuclear security. The area of detector materials would benefit from increased government investment so that good candidate materials can be rapidly developed into technologies for countermeasures to radiological and nuclear terrorism.

Thank you for your attention.

Reference 1: "The Effect of Gamma-ray Detector Energy Resolution on the Ability to

Identify Radioactive Sources”, Karl E. Nelson, Thomas B. Gosnell, David A Knapp, Lawrence Livermore National Laboratory, LLNL-TR-411374, February, 2009.

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